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Spatial Distribution of Benthic Macroinvertebrates in a Sidearm Embayment of Kentucky Lake

James B. Ramsey[1] and David S. White

Hancock Biological Station and Center for Reservoir Research, 561 Emma Drive, Murray, Kentucky 42071

and

Hwa-Seong Jin

Department of Biology, University of Louisville, Louisville, Kentucky 40292

ABSTRACT

The macrobenthos of Ledbetter Embayment, Kentucky Lake, were sampled monthly (January 2005 through July 2006) to determine community structure with focus on the physical and chemical factors influencing spatial distribution and density. We collected 38 species, including 27 insects, four mollusks, two crustaceans, and three annelids. Species composition was similar to that observed in other midwestern reservoirs except that some taxa, typically rare in other systems, were very abundant. Mean density was 1158 m^{-2} and density increased with water depth. Macroinvertebrate distribution was patchy. Profundal collector-gatherers were associated with depositional zones created by flow patterns within the embayment driven by the main stem current. Most littoral species showed associations with allochthonous input or substrate heterogeneity provided by incoming streams. The physical structure of Kentucky Lake embayments and commensurate patterns of organic matter deposition, depth, and substrate composition appear to be the primary factors structuring the macrobenthos.

KEY WORDS: macroinvertebrates, benthos, reservoir, embayment, Kentucky Lake

INTRODUCTION

Much of our understanding of benthic community structure has been derived from the study of natural lakes, streams and rivers (Brinkhurst 1974; Wetzel 2001). In the southern United States, however, many of the large, lentic ecosystems are man-made reservoirs. Indeed the surface area of reservoirs in the United States now exceeds that for natural lakes outside the Laurentian Great Lakes (Thornton 1990a). Our understanding of similarities and differences in structure and function between reservoirs and natural lakes is still lacking, and further study is needed to improve our ability to manage and use these resources (Thornton 1990a; White 1990; Wetzel 2001).

Reservoirs differ from natural lakes and rivers in a number of respects including relative drainage basin size (Thornton 1990a), stratification regime and dissolved oxygen dynamics (Cole and Hannan 1990), transport and sedimentary processes (Ford 1990; Thornton 1990b), and water retention time (Wetzel 1990). Variation in such influential characteristics likely affects the structure of benthic communities such that they are expected to differ measurably from natural lacustrine and riverine ecosystems.

Kentucky Lake is the furthest downstream of nearly 50 reservoirs on the Tennessee River system, and was constructed by the Tennessee Valley Authority for power generation, flood control and transportation in 1944. At Kentucky Dam, the Tennessee River is a 8–9th order system, creating what is termed a mainstem impoundment (Thornton 1990b). Mainstem impoundments are characterized by having a deep main channel, a comparatively narrow inundated floodplain, and numerous small sidearm embayments. Kentucky Lake has a length of 296 km, a surface area of 64,750 ha, and a shoreline of 3830 km. It has a rapid turnover time (13–37 days) controlled by Kentucky Dam, which releases water at a mean annual rate of 1800 $m^3\ sec^{-1}$ (Yurista et al. 2004). The resulting current in the main channel prevents thermal stratification. The reservoir water level is raised and lowered 1.8

[1] Corresponding author email: James.Ramsey@murraystate.edu

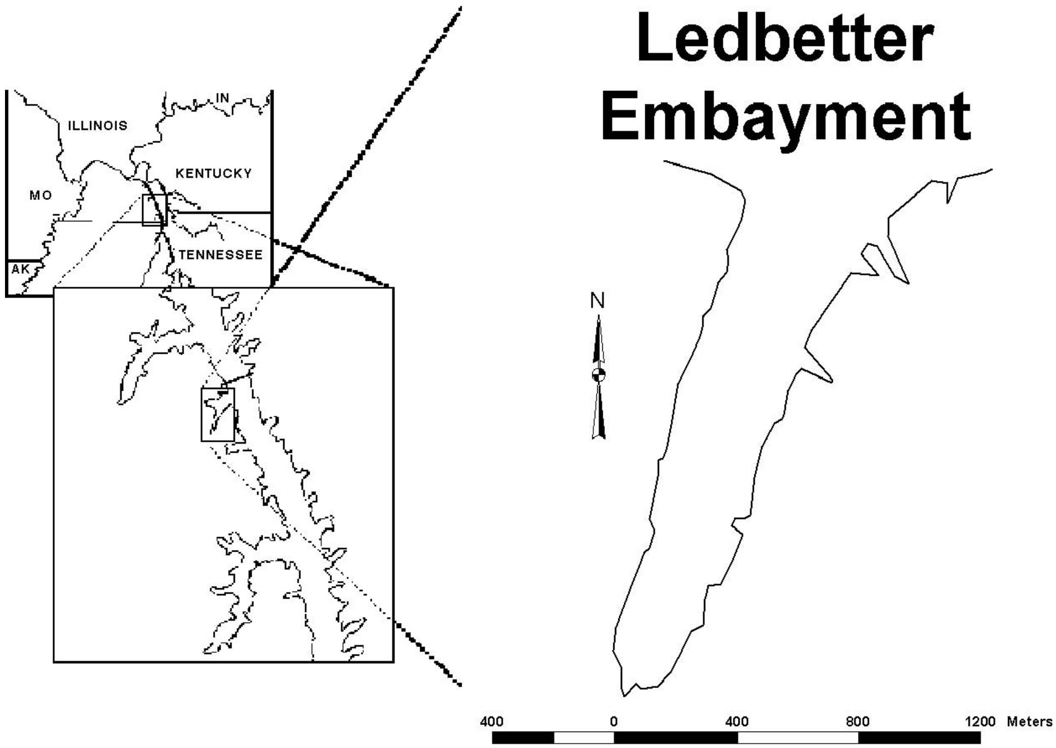

Figure 1. Location of Kentucky Lake in western Kentucky and Tennessee with detail of Ledbetter Embayment shoreline.

m each year between a high summer pool in late spring and a lower winter pool in early fall.

Seasonal drawdown, retention time, and temperature and dissolved oxygen dynamics likely affect the structure of the benthic community in the main body of the reservoir and its embayments (Furey et al. 2006). The goals of the present study were to describe the benthic community of an embayment of Kentucky Lake, examine the patterns of several environmental factors that influence benthic macroinvertebrate structure, and investigate how densities of several dominant taxa change with respect to water depth. Surprisingly little is known about reservoir benthic communities; indeed, there was no discussion of benthos in Thornton et al. (1990).

STUDY SITE

Ledbetter is a 1.2 km long, sidearm embayment located along the western shore of Kentucky Lake at Tennessee River mile 42.5 (68.4 km) (Figure 1). Ledbetter Embayment was created by inflow from Ledbetter Creek, a 3rd order stream, and is typical of bays created by 2nd to 4th order streams entering the Tennessee River. They originally were part of the river's floodplain. Most embayments have submersed bay mouth bars (Figure 2) on the downriver sides that were formed during floods prior to impoundment and that have continued to grow. The bars, in effect, create secondary impoundments with characteristic flow and deposition patterns. For Ledbetter, there is an initial counterclockwise flow pattern followed by smaller counterclockwise gyres. Where the gyres meet, water velocity is reduced resulting in zones of deposition (Figure 2). Water generally exits on the upriver side of the impoundment. Based on mean discharge of Ledbetter Creek, the residence time of water in the embayment is approximately one year (Johnson 1992).

METHODS

Macroinvertebrate sampling consisted of 40 benthic grabs taken each month (October

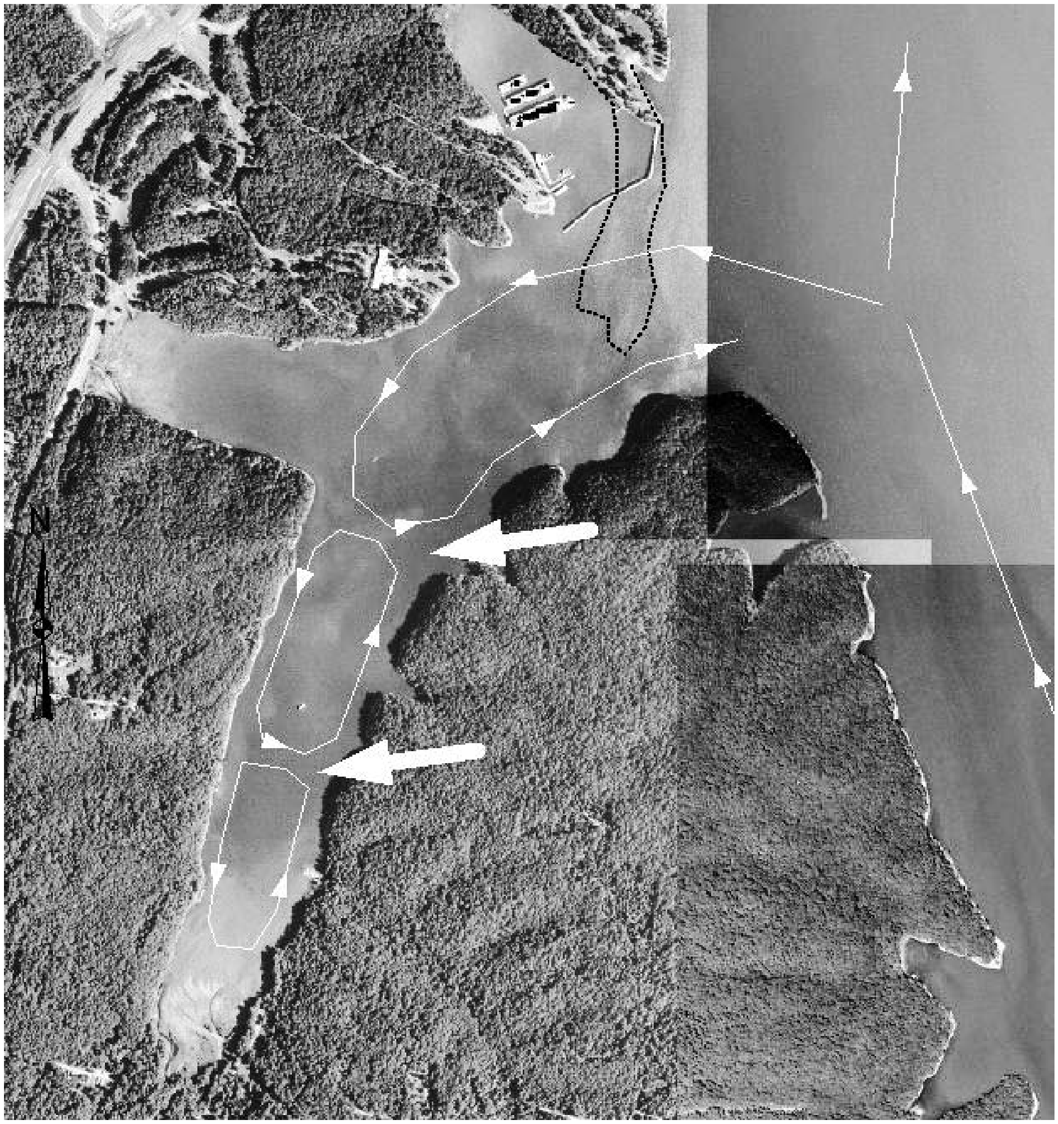

Figure 2. Surface flow patterns of Ledbetter Embayment with direction indicated by small white arrows (Johnson 1992). The submersed bay mouth bar is outlined in black. Zones of low current velocity (potential depositional zones) are indicated by the large white arrows.

2005 through July 2006 with exception of February 2006) at a set of points selected using a stratified, weighted random design. The design was stratified by 1 m depth zones and weighted by the percent area represented by each depth zone. A subset of all points available for each depth zone was taken, and its points were assigned a numerical value (1–300). A random number generator was used to select sampling points. The points were chosen from a 10 × 10 m grid overlay of the embayment with a geographically referenced point in the center of each square on the grid. Benthic samples were taken with a standard PONAR grab sampler (sampling area: 522 cm^2) at each of the selected points. Points were determined with the aid of a Global Positioning System (GPS). Contents of the PONAR were sieved through a 0.5 mm mesh bucket sieve, fixed in 10% buffered formalin containing rose bengal dye, and stored for later processing. Water depth, dissolved oxygen (DO), and temperature at the sediment water interface of each sampling point were measured with a YSI® 600 XL multiprobe sonde.

In the laboratory, formalin was rinsed from each sample before macroinvertebrates were separated from rocks, sand, and course particulate organic matter (CPOM) in white enamel pans. The contents of each pan were searched twice for macroinvertebrates. Samples containing large amounts of debris were split into several pans. Macroinvertebrates were identified, counted, and preserved in 70% ethanol. Coarse particulate organic matter was washed from rocks, sand, and empty mollusk shells using running water and a 0.5 mm sieve, dried for 48 hrs at 40°C, and weighed (±0.01 g).

During January 2006, 100 sediment cores were taken from the embayment with the sampling design described above using a 5.08 cm diameter (2 in) gravity corer. The top 2 cm of sediment from each core was extruded, dried at 40°C for 48 hr, and homogenized. Ash-free dry mass of an 8–20 g subsample was determined by heating it at 550°C for 4 hr then reweighing (±0.01 g). An estimate of the percent combustible organic matter of the sediment samples was obtained by dividing the percent combustible material in half (APHA 2005).

Linear regression was used to analyze the density of several prominent macroinvertebrate taxa against depth using the entire dataset. As some densities were low and many samples contained few or no individuals of some taxa as a result of patchy distribution, a log transformation was used to reduce variance and satisfy normality assumptions (Bartlett 1947; Box and Cox 1964). For each month, temperature and dissolved oxygen concentration were each regressed against depth. Also, the dry mass of CPOM was regressed against depth. All regression calculations were made using SAS® 9.1 (SAS Institute, Inc., Cary, NC). The distributions and densities of taxonomic groups were mapped with ArcView GIS software and compared visually using map overlays of the distribution of sediment organic matter obtained from core content analysis.

RESULTS

Thirty eight macroinvertebrate taxa were collected from the benthos of Ledbetter Embayment (Table 1). The mean density was 1158 m^{-2} with a range of 0–5000 m^{-2}. Distribution was patchy (standard deviation = ±638 macroinvertebrates m^{-2}). Few macroinvertebrates were collected from a submerged roadbed located near the western shore or from areas of the shore with exposed chert gravel and cobble. With few exceptions, the only invertebrates collected from such rocky habitats were tube-dwelling *Chironomus* larvae and *Stenonema* naiads. Regression results suggested a weak increase in macroinvertebrate density with depth ($r^2 = 0.016$, $P = 0.0344$).

The dry mass of CPOM in samples decreased with depth ($r^2 = 0.3269$, $P < 0.0001$). Patches of sandy substrate were present in channels extending from Ledbetter Creek, a spring on the western shore, and a few other small stream inlets. Below a depth of three meters, there was very little CPOM and the substrate was predominantly soft clay. Temperature decreased with depth ($R^2 = 0.16$–0.87, P 0.0116 to < 0.0001), with the exception of the January and May samples when there was no detectable relationship between temperature and depth. Temperature varied less than 3°C among sampling locations each month. Dissolved oxygen concentrations increased with decreasing water depth during all sampling dates ($r^2 = 0.37$–0.78, $P < 0.0001$). Concentrations varied less than 3 mg l^{-1} from October through May. In June and July when DO at water depths ≥4 m dropped to 3–5 mg l^{-1}, shallow areas became supersaturated with oxygen due to high rates of algal photosynthesis.

Map overlays indicated that greater densities of oligochaetes, including both *Limnodrilus* and *Branchiura,* and the fingernail clam, *Pisidium,* were found in association with areas of greater sediment organic matter including both the deepest (5–8 m) area on the northeastern end of the embayment and near a spring outlet on the southwestern edge (Figure 3). *Limnodrilus* and *Pisidium* densities increased with depth ($r^2 = 0.2829$, $P = 0.0054$ and $r^2 = 0.1184$, $P = 0.0296$, respectively) (Table 2). Several species of Chironominae, particularly *Chironomus major* Wülker and

Table 1. Macrobenthic taxa collected from Ledbetter Embayment.

Order	Family	Genus/species
Diptera	Chironomidae	*Coelotanypus tricolor* (Loew)
Diptera	Chironomidae	*Coelotanypus scapularis* (Loew)
Diptera	Chironomidae	*Procladius* sp.
Diptera	Chironomidae	*Ablebesmyia annulata* (Say)
Diptera	Chironomidae	*Microchironomus nigrovittatus* (Malloch)
Diptera	Chironomidae	*Cryptochironomus blarina* Townes
Diptera	Chironomidae	*Tribelos jucundum* (Walker)
Diptera	Chironomidae	*Polypedilum halterale* (Coquillett)
Diptera	Chironomidae	*Cladopelma* sp.
Diptera	Chironomidae	*Chironomus major* Wülker and Butler
Diptera	Chironomidae	*Chironomus crassicaudatus* Malloch
Diptera	Chironomidae	*Chironomus decorus* Johannsen
Diptera	Chironomidae	*Chironomus plumosus* (Linnaeus)
Diptera	Chaoboridae	*Chaoborus punctipennis* (Say)
Diptera	Ceratopogonidae	sp.
Ephemeroptera	Ephemeridae	*Hexagenia bilineata* (Say)
Ephemeroptera	Caenidae	*Caenis* sp.
Ephermeroptera	Heptageniidae	*Stenonema* sp.
Megaloptera	Sialidae	*Sialis velata* Ross
Trichoptera	Hydroptilidae	*Oxyethira* sp.
Trichoptera	Leptoceridae	*Oecetus* sp.
Trichoptera	Polycentropodidae	*Cyrnellus fraternus* (Banks)
Odonata	Coenagrionidae	*Enallagma* sp.
Odonata	Lestidae	*Lestes* sp.
Odonata	Corduliidae	*Macromia* sp.
Odonata	Gomphidae	*Progomphus* sp.
Coleoptera	Elmidae	*Dubiraphia* sp.
Mysidadaecea	Mysidae	*Taphromysis louisianae* (Banner)
Haplotaxida	Tubificidae	*Limnodrilus hoffmeisteri* Claparède
Haplotaxida	Tubificidae	*Limnodrilus udekemianus* Claparède
Haplotaxida	Tubificidae	*Branchiura sowerbyi* Beddard
Rhynchobdellida	Glossiphoniidae	*Placobdella* sp.
Architaenioglossa	Viviparidae	*Campeloma* sp.
Neotaenioglossa	Pleuroceridae	*Pleurocera* sp.
Unionoida	Unionidae	*Quadrula quadrula* (Rafinesque)
Veneroida	Corbiculidae	*Corbicula fluminea* (Müller)
Veneroida	Pisidiidae	*Pisidium compressum* Prime
Veneroida	Dreissenidae	*Dreissena polymorpha* (Pallas)

Butler, were found in greater densities as depth increased ($r^2 = 0.0767$, $P < 0.0001$). Larval densities of Ceratopogonidae, Tanypodinae and *Chaoborus punctipennis* (Say) also increased with depth ($r^2 = 0.1142$, $P < 0.0001$; $r^2 = 0.0235$, $P = 0.0113$; and $r^2 = 0.1605$, $P < 0.0001$, respectively). *Placobdella, Corbicula fluminea* Müller, *Lestes, Enallagma, Oxyethera,* and *Macromia* were found primarily near the mouth of the spring inlet on the southwestern edge of the embayment. Larval densities of *Sialis velata* Ross were not significantly related to depth. Densities of *Caenis* and *Hexagenia bilineata* (Say) naiads, *Placobdella,* and *Gammarus* were all weakly inversely related to depth ($r^2 = 0.1099$, $P < 0.0001$; $r^2 = 0.0177$, $P = 0.0284$; $r^2 = 0.1614$, $P < 0.0001$; and $r^2 = 0.1724$, $P < 0.0001$).

DISCUSSION

The species composition of the Ledbetter Embayment macrobenthos was not greatly different from that of several other midwestern reservoirs, including Lake Texoma (Sublette 1957; Vaughn 1982), Arcadia Lake (Bass 1992), Keystone Reservoir (Ransom and Dorris 1972), Arbuckle Lake (Parrish and Wilhm 1978), and Ham's Lake (Ferraris and Wilhm 1977). Although we report lower species richness in comparison to the studies just mentioned, this is likely due to the sampling method we employed. It excluded smaller organisms (<0.5 mm) and did not include depths less than 0.5 m, whereas other studies often employed multiple collection methods and were driven by qualitative rather than quantitative goals which included taxa such as watermites, and nematodes (Sublette 1957). Also, we did not collect beyond the reach of our sampling boat into the littoral zone to a depth of less than 0.5 m.

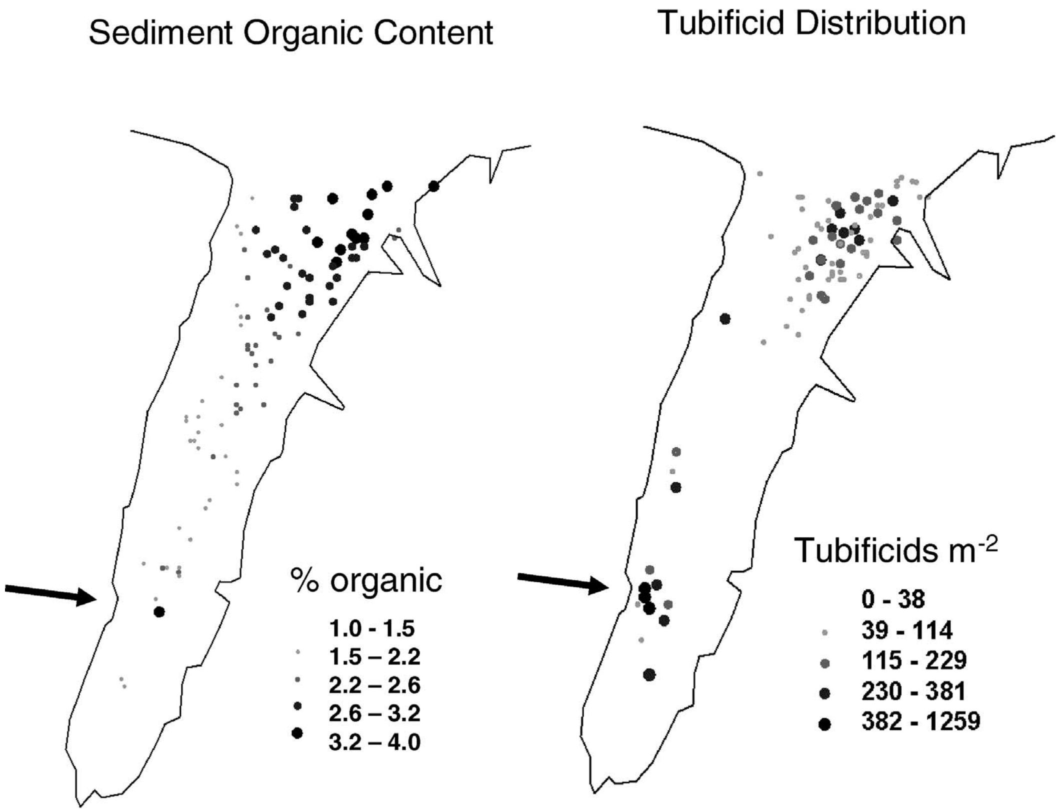

Figure 3. Distribution of sediment organic matter, measured as ½ of % combustible material from subsample (left) and tubificid distribution and density (right). Arrows indicate location of stream inlet.

We recorded several species of interest including the mysid shrimp *Taphromysis louisianae* Banner and the chironomid *Chironomus major* Wülker and Butler. Only a single *T. louisianae* specimen was collected during our study, however, this species is generally found in Gulf Coast regions and has only recently been documented in Ohio marshes (Reeder and Hardin 1992) and the littoral regions of Kentucky and Guntersville Lakes (both Tennessee River impoundments) (Brooks et al. 1998). It appears to be a naturalized species and is a common item in the diet of juvenile largemouth bass (Dreves 1997). *Chironomus major* has been recorded from a few southeastern U.S. reservoirs, but the very conspicuous, blood-red, up to 60 mm long larvae has been considered to be uncommon to rare. It has become the dominant profundal deposit feeder in Kentucky Lake, often reaching densities of 500 larvae m^{-2}. At such densities, *C. major* densities far exceed the only other available figure for *C. major* (Balci et al. 2005), where the maximum density reported in Kentucky Lake was 196 larvae m^{-2}.

The depth trends in macrobenthos density in Ledbetter Embayment were different from trends reported for other reservoirs. Because several other studies on the benthos of reservoirs with seasonal water level fluctuation showed that macroinvertebrate density and biomass tended to be higher immediately below the drawdown zone (Kaster and Jacobi 1978; Furey et al. 2004, 2006), we had expected that macrobenthos density would be greater at 0.5 to 1 m. In Ledbetter Embayment, however, when macroinvertebrate density was plotted against depth, there was a weakly positive yet significant trend despite high variance (Figure 3). The patchy distributions that we observed are not uncommon in the lentic environment, and we suspect that

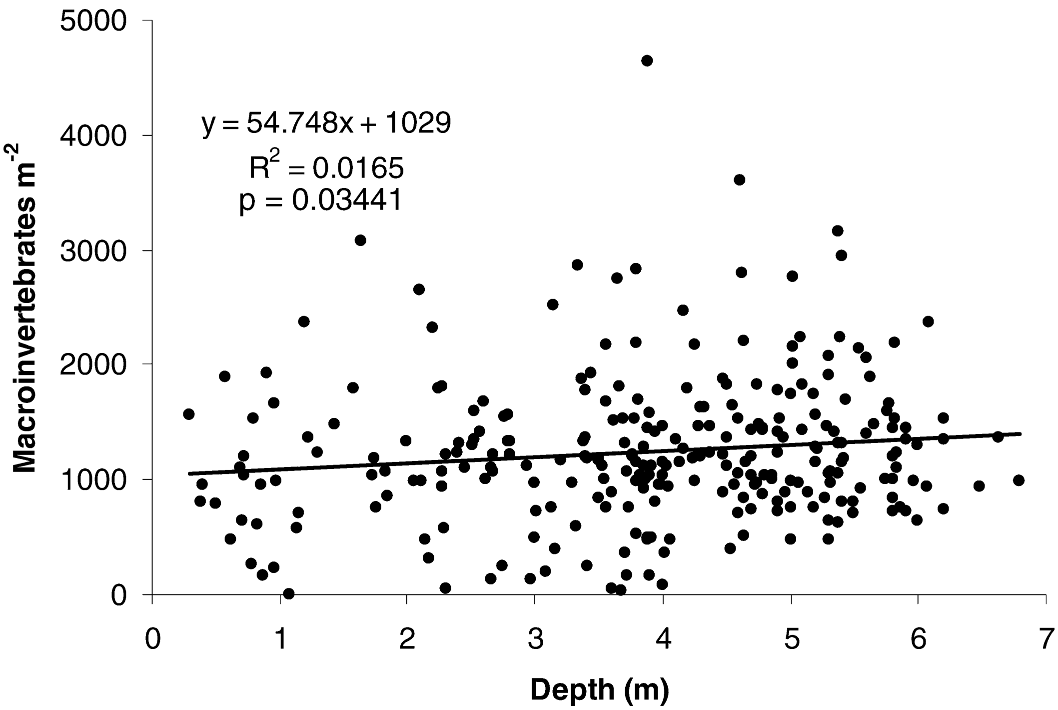

Figure 4. Macroinvertebrate density plotted against depth in Ledbetter Embayment of Kentucky Lake.

a variety of factors contribute to the variable spatial pattern including sediment reworking by benthic organisms, physical variation in the bottom profile (Downing and Rath 1988), and variation in sediment grain size (Sauter and Gude 1996).

Two separate combinations of factors appear to be influencing macroinvertebrate spatial distribution and density in the littoral and profundal zones. Streams entering the embayment are the primary influence in the littoral and sublittoral zones. The erosive force that streams exert and the allochthonous organic matter that they introduce to the system shape the substrate and provide an important food source. The substrate heterogeneity created by erosional forces, exerted by incoming stream inlets, is important for providing suitable habitat for many macroinvertebrates (Brinkhurst 1974). The patches of sand and gravel created by stream flow are particularly important to invertebrates such as *Oxyethira* that do poorly in depositional areas (Wiggins 1996). The influx of allochthonous organic matter is important in shallower regions, especially where it concentrates adjacent to incoming stream channels. The separate and unique assemblage of species inhabiting shallower water suggests that the greater availability of CPOM deposited near shore serves as an important substrate and food source.

Evidence presented here suggests that the pattern of particulate organic matter deposition and depth are important factors influenc-

Table 2. Density regressed with depth for 13 macroinvertebrate taxa in Ledbetter Embayment.

Taxon	Slope	F	*P*	r^2	n
Branchiura	NS	0.689	0.4071	0.0025	271
Caenis	−0.2151	33.23	<0.0001	0.1099	271
Ceratopogonidae	0.457	34.7	<0.0001	0.1142	271
Chaoborus	0.5269	51.455	<0.0001	0.1605	271
Chironominae	0.2127	22.37	<0.0001	0.0767	271
Corbicula	−0.0343	16.16	0.0002	0.2983	40
Gammarus	−0.3651	56.053	<0.0001	0.1724	271
Hexagenia	−0.1644	4.852	0.0284	0.0177	271
Limnodrilus	0.2507	7.834	0.0054	0.2829	271
Pisidium	0.5237	5.104	0.0296	0.1184	40
Placobdella	−0.3617	51.789	<0.0001	0.1614	271
Sialis	NS	3.292	0.0707	0.0121	271
Tanypodinae	0.1561	6.5	0.0113	0.0235	271

ing the profundal macroinvertebrate community structure in Ledbetter Embayment. Areas of greater sediment carbon content, indicative of greater organic matter deposition, support higher densities of profundal deposit feeders (Figures 2, 3). The distribution of oligochaetes was most strongly influenced by organic matter deposition patterns as evidenced by the densely populated patches that coincided with higher sediment organic content revealed using GIS map overlays. In the case of Ledbetter Embayment, and likely in embayments with similar morphology, the direction and velocity of flow propelled by the main-stem current determine where POM deposition occurs. DO levels tend to sag during the summer at water depths of greater than 4 m, and sags may be sufficient to exclude or limit the activities of some taxa. Reduced DO concentrations may have been sufficient to account for the reduced number of tanypod larvae that we observed at depths greater than 5 m despite the positive relationship with depth that linear regression revealed (Table 2).

The distribution and density of the macrobenthos in other 3rd to 4th order stream embayments of Kentucky Lake may be influenced by similar factors. Most of the embayments share morphological characters such as baymouth bars and circulation patterns driven by the mainstem current. This set of conditions appears to be favorable for some taxa that generally are rare in most lakes and reservoirs (e.g., *Chironomus major, Taphromysis*), while reducing populations of species that might be expected to be more common (*Hexagenia*). In order to better understand the structure of benthic communities, it would be of value to determine if other mainstem reservoirs have similarly structured embayments and if the embayments in much more dendritic tributary impoundments (Thornton 1990a) provide the same sets of conditions. More studies like this will not only further our understanding of factors influencing macrobenthos structure in reservoirs, but will serve to clarify the differences between reservoirs and natural lakes thereby improving our ability to manage reservoirs effectively.

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